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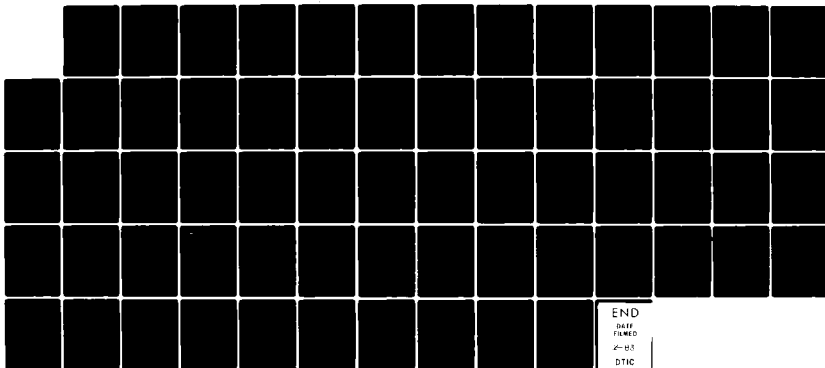
FIELD TESTING OF GEOPHYSICAL TECHNIQUES(U) D'APPOLONIA  
CONSULTING ENGINEERS INC PITTSBURGH PA R L COSTELLO  
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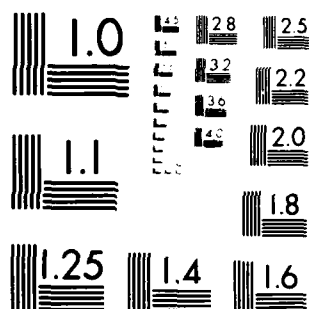
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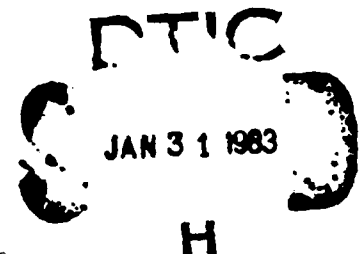
# Field Testing of Geophysical Techniques

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Aberdeen Proving Ground, MD 21010

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report presents the results of the Phase II effort to field test geophysical techniques identified during Phase I as being potentially useful for shallow geologic and aquifer analysis. For clarification, "shallow" is defined to mean depths less than 300 feet although none of the tested techniques are inherently limited to this range. Included in the report is a geologic and physiographic description of the test site and a summary of the field plan. Following is a discussion of field operations and procedures, data processing, results, and a summary which considers the effectiveness of the tested techniques and presents recommendations.		

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## 1.0 INTRODUCTION

This report presents the results of the Phase II study to implement geophysical techniques which are applicable to shallow geologic and aquifer analysis. This study has been conducted under Government Contract No. DAAK11-80-C-0029 entitled "Development of Geophysical Techniques for Installation Restoration" and represents the final effort in an overall program to develop geophysical techniques for installation restoration.

## 1.1 BACKGROUND

The United States Army Toxic and Hazardous Materials Agency (USATHAMA) has been assigned responsibility to identify and contain or eliminate all toxic and hazardous materials which have the potential to migrate beyond post boundaries at specific Department of Defense installations. Existing subsurface data are limited to borehole information. In order to expand the subsurface data base in a cost-effective manner, a decision has been reached to investigate the feasibility of using various geophysical techniques for this purpose. The additional data would be used as input to the decision-making process for abating contamination problems.

The program to investigate the feasibility of using geophysical techniques to expand the subsurface data base is divided into two phases. Phase I, which is complete, consists of identifying and describing geophysical techniques that can be advantageously applied to shallow geologic and aquifer analysis. The results of Phase I have been reviewed by USATHAMA and published as Report No. DRXTH-TE-CR-80084 entitled "Identification and Description of Geophysical Techniques".

Phase II, which reaches completion with this report, consists of planning, executing, and interpreting field surveys at the Volunteer Army Ammunition Plant (VAAP) in Chattanooga, Tennessee to provide actual field data for evaluating the application of geophysical techniques to installation

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restoration. The planning for Phase II is described in a separate previous report entitled "Test Plan: Application of Geophysical Techniques".

The following geophysical techniques were implemented in Phase II:

- Seismic Refraction
- Vertical Electrical Sounding (VES) Resistivity
- Horizontal Profiling (HP) Resistivity
- Gravity

Complete discussions of these techniques may be found in the Phase I Report.

## 1.2 DESCRIPTION OF REPORT CONTENT

A summary of the field plan is contained in Chapter 2.0. This summary consists of a general physiographic and geologic description of VAAP and specific descriptions of the two selected test sites. Also presented are the extent and layout of the various geophysical surveys conducted at VAAP. Chapter 3.0 provides a discussion of field operations and procedures. Data processing is covered in Chapter 4.0 while the results are presented in Chapter 5.0. A summary is presented in Chapter 6.0 which includes a discussion of the effectiveness of the geophysical techniques and recommendations for future geophysical surveys.

## 2.0 FIELD PLAN SUMMARY

## 2.1 GENERAL TEST SITE DESCRIPTION

VAAP is located in the Appalachian Valley and Ridge physiographic province which extends from New York to Alabama and has an average width of 50 miles. The province is characterized by northeast-southwest trending valleys and ridges. This unit is flanked on the east by the Blue Ridge Mountains and on the west by the Appalachian Plateau. Elevations above mean sea level within VAAP range from 680 feet at the southwestern corner to 1,100 feet in the southern part of the magazine area. The eastern half of the installation is hilly and contains steep to moderate slopes. The western half of VAAP is a wide valley with gently rolling topography. This valley rises abruptly to a ridge along the western boundary. All VAAP manufacturing areas are located within the valley. A few sinkholes are scattered throughout the eastern hilly portion of the installation, but a greater density of sinkholes exists in the northern portion of the manufacturing valley. Some of these sinks are relatively old and plugged with clay while others are relatively recent and are actively forming.

The Appalachian Valley and Ridge Province is a region of folded, faulted, and deformed rocks of Paleozoic age, consisting mainly of limestones, dolomites, shales, and some sandstones. During the geologic past, mountain building forces compressed the strata into tight folds which were finally broken by thrust faults which are generally parallel to the axial planes of the folds. This faulting has produced a repetition of formations in a series of overlapping fault blocks with fault planes generally dipping to the southeast. These formations crop out in relatively narrow linear belts along ridges. The intervening valleys are generally underlain by broader open folds than the ridges and bedrock is only occasionally exposed. Residual clays containing abundant chert and limestone fragments mantle the bedrock and extend as deep as 200 feet in places. The chert fragments, which are the weathering product of dolomite and siliceous limestones, occur in all sizes up to

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large, irregular-shaped boulders and become more abundant with depth. Solution channels and cavities have developed along numerous joints and fractures in the soluble limestones and dolomites underlying the valleys. Consequently, the bedrock surface is extremely irregular and pinnacled. Resultant voids in the overburden are usually bridged by interlocking chert fragments and filled with soft soil.

The manufacturing valley located in the western portion of VAAP is situated over a syncline which consists of the Copper Ridge Dolomite and shales of the Conasauga Group. Soil borings located in the Administration, Railroad Yard, New TNT, and New Acid Areas show that the overlying residuum is about 30 to 60 feet thick. However, it is significantly deeper under some of the topographic highs. A few of the soil borings found cavities up to 9 feet deep at the base of the residuum. The residuum consists of red and yellow, acidic, impermeable clay with some silt, chert, and dolomite fragments. The central portion of VAAP is underlain by shales of the Conasauga Group. The overlying material ranges from 0 to 15 feet deep and consist of yellow, acidic, impermeable clay. The rugged eastern portion of VAAP is mantled by residuum which ranges in thickness from 90 feet under the valleys to 150 feet beneath the hills. This residuum is similar to that found in the western portion of VAAP except that it contains more chert fragments. The bedrock in the eastern portion consists of carbonates of the Knox Group.

The Copper Ridge Formation beneath the manufacturing valley is an aquifer and has a water table located at or near the bedrock surface. Borings in the New TNT area encountered groundwater at depths of 45 to 52 feet. The far west and central portions of VAAP are not potential sources of groundwater because the underlying Conasauga shales form an impermeable aquiclude. The eastern half of VAAP is underlain by an unconfined aquifer in the Knox Group carbonates with a water table located near the bedrock surface at an average depth of about 120 feet.

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## 2.2 NORTHERN PERIMETER ROAD

### 2.2.1 Site Description and Objectives

The first test site is located in the northern end of the manufacturing valley situated in the western portion of VAAP. This test site is situated over a syncline which consists of the Copper Ridge Dolomite Formation. The overlying residuum is about 30 to 60 feet thick and consists of red and yellow, acidic, impermeable clay. This test site was selected for the following reasons:

- The northern half of the manufacturing valley is topographically isolated from the southern half and is therefore believed to influence drainage and groundwater movement in the surrounding area. Presumably, the direction of groundwater movement is to the north and out of the confines of VAAP.
- The northern half of the manufacturing valley contains the greatest density of sinkholes in VAAP. Those sinkholes could act as conduits for the introduction of pollutants into the Copper Ridge aquifer.
- Several potential sources of pollution exist in the surrounding area including redwater ash disposal sites, redwater storage ponds, and chemical storage tanks.

The primary objectives of geophysical surveys at this test site are to delineate the bedrock and potentiometric surfaces and to determine the existence and extent of dissolution features. Figure 1 shows the location of this test site.

### 2.2.2 Test Coverage

The geophysical coverage at the Northern Perimeter Road site is shown in Figure 1. Line NP-1 is a continuous seismic refraction profile approximately 3,600 feet in length which commences near Gate 3 and parallels the Northern Perimeter Road across the northern end of the manufacturing valley. Spaced at approximately even intervals along Line NP-1 are 10 VES resistivity soundings (R1-R10) plus two supplemental soundings (R11

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and R12). This coverage is designed to provide bedrock and potentiometric surface profiles across the valley as well as to delineate any dissolution features which may be intersected. This coverage is consistent with that specified in the test plan except that several of the VES soundings are located slightly offline to avoid metal objects.

Seismic refraction and VES resistivity surveys have been selected at this site because large velocity and/or resistivity expressions are believed to exist based on local geology. Characteristic geophysical parameters for VAAP are discussed in Chapter 5.0.

### 2.3 NEW ACID AREA

#### 2.3.1 Site Description and Objectives

The second test site is located in the New Acid Area on the eastern flank of the northern end of the manufacturing valley. Geologically, this test site is similar to the Northern Perimeter Road site, but is generally characterized by a thicker layer of residuum. Existing borings in the New Acid Area show bedrock at depths ranging from 20 to over 124 feet. This test site has been selected primarily due to the existence of sink holes, one of which is currently developing under the D-402 soda ash storage tank. These sink holes could provide conduits for the introduction of pollutants into the Copper Ridge aquifer as evidenced from the 1943 redwater ash contamination incident at VAAP.

The primary objectives of geophysical surveys at this test site are to determine the existence and extent of dissolution features and to delineate the bedrock and potentiometric surfaces. Figure 1 shows the location of this test site.

#### 2.3.2 Test Coverage

The geophysical coverage at the New Acid Area site is shown in Figure 2. Lines NAS-1, NAS-2, and NAS-3 are southeast-northwest seismic refraction lines with respective lengths of 415, 660, and 660 feet. Lines NAS-4, NAS-5, and NAS-6 are southwest-northeast seismic refraction lines with

equal lengths of 660 feet. Lines NAR-2 and NAR-3 are HP resistivity lines which coincide with lines NAS-2 and NAS-3 and begin at Row 1. The length of each HP resistivity line is 510 feet. VES-1 through VES-12 are VES resistivity points. The open circles in Figure 2 are located across the site on a 30-foot grid and are gravity measuring points. The total coverage at the New Acid Area site is 3,715 feet of seismic refraction profile, 1,020 feet of HP resistivity profile, 12 VES resistivity points, and 261 gravity measurements. This coverage is designed to locate and determine the extent of dissolution features as well as to map the bedrock and potentiometric surfaces. Additionally, the coverage takes advantage of control from boreholes drilled prior to construction. This coverage is consistent with that specified in the Test Plan except that the seismic refraction and HP resistivity lines have been lengthened, the southeast-northwest electrode expansion at VES-4 has been eliminated to avoid a debris pile between VES-11 and VES-12, and VES-13 has been eliminated to avoid a metal fire protection main along the roads edge. Two VES points have been added at the Northern Perimeter Road site to compensate for these eliminations. Finally, gravity points at K-8, L-8, M-8, and H-3 have been moved to L-3, M-3, N-3, and O-3 to avoid debris piles.

The geophysical techniques employed at this site have been selected because they respond directly to the large velocity, resistivity, and density expressions which are believed to exist based on local geology. Characteristic geophysical parameters for VAAP are discussed in Chapter 5.0.

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### 3.0 FIELD OPERATIONS AND PROCEDURES

Field operations were conducted during February and March 1981. The seismic refraction and resistivity surveys were completed in twelve working days by a three-man crew. The gravity survey was completed in four working days by a one-man crew. No adverse weather or working conditions were encountered.

#### 3.1 SEISMIC REFRACTION PROCEDURES

The seismic refraction field procedure employed at VAAP was reversed profiling. This procedure consists of the following steps:

- Twelve geophones are arranged in a linear spread along the line of profile with a horizontal spacing between geophones of 15 feet.
- Shots are fired in the middle of the spread, at both ends, and off both ends at a distance of 165 feet. Seismic records are made for each individual shot point.
- The geophones are moved 165 feet down the line of profile and the procedure is repeated until the line of profile is completed.

The equipment used for refraction surveys at VAAP consisted of the following:

- Geometrics/Nimbus ES-1210F seismograph
- Betsy Seisgun source
- Mark Products 8 Hz geophones
- Mark Products 12-channel cables

#### 3.2 RESISTIVITY PROCEDURES

Two different field procedures for resistivity surveys were used at VAAP. The first procedure was vertical electrical sounding (VES) using the Schlumberger electrode configuration. This procedure consists of placing four electrodes in line about the measuring point. The outer electrodes are connected to a current source and the inner electrodes are connected to a potentiometer. While transmitting a known current

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The second resistivity procedure used at VAAP was horizontal profiling (HP) using the dipole-dipole configuration. This procedure consists of measuring the potential across two inline electrodes while successively activating current dipoles at increasing distances along the line of profile. The fixed potential electrodes are then moved one increment down the line and the process is repeated. The increment used at VAAP was 30 feet with a maximum dipole separation of 210 feet.

- Phoenix RT-1 current source.
- Phoenix RT-1 potentiometer.
- Stainless steel current electrodes.
- Porous pot potential electrodes.

Gravity measurements at VAAP were made using the microgravimetric procedure. This procedure consists of placing a gravimeter at closely-spaced points on a grid and noting the gravity reading. Also, measurements are taken frequently at a base station to monitor temporal drift. Every effort is made to insure instrumental stability including care in handling and a 30 minute rest period after vehicular transportation before any measurements are made. For the gravity survey at VAAP, the grid spacing was 30 feet and the base station was reoccupied every hour. Instrumentation consisted of a LaCoste-Romberg Microgal D gravimeter.

Land surveying was subcontracted to Action Consultants Incorporated of Chattanooga, Tennessee. A three-man crew completed the field work in three days spending approximately one-and-a-half days at each site. The

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The VAAP plant grid has no known relation to longitude/latitude or to the State Planar System or UTM System as of this report date. Horizontal and vertical accuracy of all surveyed points was  $\pm 0.01$  foot.

## 4.0 DATA PROCESSING

### 4.1 SEISMIC REFRACTION PROCESSING

All seismic refraction data collected at VAAP were processed using computer program FSIP (Fast Seismic Interpretation Program) developed by the U.S. Bureau of Mines. The processing sequence is as follows:

- Arrival times are picked by the interpreter from the field records for each spread.
- The arrival times are input to the computer along with horizontal and vertical coordinates for the shot points and geophones.
- Program FSIP constructs a time-distance plot which accounts for elevation differences.
- The interpreter divides each time-distance plot into a series of straight line segments and assigns a layer number to each straight segment. This information is input to the computer.
- Program FSIP performs a velocity analysis on each straight line segment and outputs a table of velocities for each spread.
- The interpreter selects a reasonable velocity model based on the velocity analyses for all spreads in one area. FSIP permits the interpreter to enter a velocity model which remains constant or varies laterally.
- Program FSIP inverts the data using delay-time and raypath-tracing methods and produces a cross section showing layer boundaries for each spread.

### 4.2 RESISTIVITY PROCESSING

The VES resistivity data gathered at VAAP were processed using computer program CRIMPA (Complete Resistivity Interpretation and Modelling Package Automatic) developed by Dr. Charles Stoyer of the Colorado School of Mines. The processing sequence used is listed below:

- The interpreter inputs the apparent resistivity as a function of electrode spacing for each test location.

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- Program CRIMPA inverts the data using a multi-layered model. The output consists of a list of layer thicknesses and resistivities and a correlation coefficient. The interpreter may specify the number of layers to be used or CRIMPA will select a likely model based on statistical considerations.
- The interpreter examines the inverted results for each test location to see if they are reasonable. At his discretion, the interpreter may select a new model by specifying a different number of layers or may refine a model by specifying layer thicknesses and resistivities. Additionally, the interpreter can edit out data points that he feels are bad due to external effects such as buried metal pipes.
- The process is repeated until the interpreter arrives at a model that is both geologically sound and statistically valid. For the resistivity data at VAAP, a minimum statistical correlation of 90 percent was required although all but a few points had a statistical correlation better than 95 percent.

The HP resistivity data gathered at VAAP were processed in the field by hand using the formula:

$$\rho = \pi \left( \frac{A^3}{B^2} - A \right) \frac{V}{I}$$

where

- $\rho$  = apparent resistivity
- A = dipole separation
- B = dipole length
- V = measured voltage
- I = input current

For each measurement made, the apparent resistivity was plotted on a cross section at a point midway between the measuring dipoles at a depth equal to one-half the dipole separation.

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#### 4.3 GRAVITY PROCESSING

The gravity data collected at VAAP were processed by computer using program GRAVD developed by John Fett of Earth Sciences Incorporated. This program requires no interaction on the part of the interpreter other than to input data consisting of the station number, latitude, longitude, gravimeter reading, date, and time. Program GRAVD then proceeds as follows:

- The data are corrected for elevation and Bouguer slab using a specified density. For the VAAP survey the density used was 1.9 g/cc.
- The data are corrected for changes in latitude by calculating the local geodetic gradient.
- The data are corrected for tides by computing the tidal effect for the date and time of the measurement and subtracting it.
- The data are corrected for temporal drift by prorating successive base station mistakes about the respective loop.

Additionally, the VAAP gravity data were corrected for regional gradient.

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## 5.0 RESULTS

### 5.1 NORTHERN PERIMETER ROAD

#### 5.1.1 Seismic Refraction Results

The results of the seismic refraction survey (Line NP-1) are shown in Figure 3. (Refer to Figure 2 for the location of subsurface coverage.) The estimated resolving power of the seismic refraction survey permits detection of features as small as 15 feet in size. Layer depths are believed to be accurate to within ten percent. The abscissa is the inline coordinate (distance measured along the line from the easternmost end) in feet and the ordinate is MSL elevation in feet. The VAAP coordinates for Line NP-1 are listed in Table 1. Three distinct layers are depicted and are described below in order from top to bottom.

Layer 1 has a velocity of 1,410 ft/sec and is interpreted to be a thin layer of relatively loose and uncompacted clays, silts, and chert fragments with a maximum thickness of approximately 15 feet. This layer is generally thicker in the bottom and on the west side of the valley.

Layer 2 has a velocity of 3,200 ft/sec between inline coordinate 0 feet and 970 feet increasing linearly to 5,300 ft/sec between inline coordinate 970 feet and 1,940 feet and then remaining constant at the higher velocity to the west end of the line. Layer 2 is interpreted to consist of slightly moist clays to the east with the water content increasing and causing the higher velocities to the west.

Layer 3 has a velocity of 14,500 ft/sec and is interpreted on the basis of local geology to be carbonate bedrock. Note that the top surface of Layer 3 is highly irregular and is generally deeper on the west side of the valley. Also note that the deeper bedrock to the west corresponds to the increasing water content in Layer 2. Of interest on the bedrock surface are a "pinnacle" at inline coordinate 600 feet and a "trough" near inline coordinate 2,300 feet. The bottom of the trough descends to

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elevation 626 feet and is the lowest point in the bedrock surface anywhere across the valley. No positive indication of dissolution features is present, but they may be indicated by the numerous isolated depressions in the bedrock surface.

#### 5.1.2 Vertical Electrical Sounding Results

The results of the VES along Line NP-1 are also shown in Figure 3. Layer depths are believed to be accurate to within 20 percent. The abscissa and ordinate are the same as for the seismic refraction profile. VAAP coordinates for all VES are listed in Table 2. Note that due to perturbing effects of metal fences and pipes, all sounding points except R1, R4, and R10 were displaced approximately 100 feet perpendicular to the line. Data from sounding points R4, R5, R9, R10, and R12 yielded best fit models with three layers while data from the remaining sounding points yielded best fit models with four layers. These layers are described from top to bottom.

Layer 1 is a thin layer immediately beneath the surface with a mean resistivity of 205 ohm-meters. This layer reaches a maximum thickness of approximately 10 feet at sounding point R5, but is elsewhere generally less than 3 feet in thickness. Layer 1 is believed to be composed of relatively loose and uncompacted clays, silts, and chert fragments that were saturated by heavy rainfall just prior to commencement of the field program. This layer is not observed at R9 and R12 possibly due to R9 being located at a topographically high, well-drained area and R12 being located along the edge of a bank which is also well drained.

Layer 2 has a mean resistivity of 960 ohm-meters and thickens as the elevation of the valley floor increases. This layer is not observed at sounding points R4 and R5. The maximum thickness of Layer 2 is about 36 feet at sounding point R9. Layer 2 is interpreted to consist mainly of slightly moist clays and chert fragments. The absence of this layer at sounding points R4 and R5 is probably caused by the saturating effects of a creek which flows through the bottom of the valley.



Layer 3 has a mean resistivity of 90 ohm-meters and is interpreted to indicate a zone of water-saturated clays. This layer appears at all twelve sounding points and attains a maximum thickness of about 68 feet at R8. The lowest elevation for the top surface of this layer is 685 feet at R5. The abrupt change in elevation of the top of Layer 3 between R12 and R8 may be explained by the fact that R12 is approximately 100 feet south of Line NP-1 while R8 is about 100 feet north. It is very likely that the top of Layer 3 is the water table or is a water-saturated clay surface similar in shape to the water table which is located at some unspecified distance above.

Layer 4 has a mean resistivity of 505 ohm-meters and is interpreted to indicate carbonate bedrock. The lowest elevation for the surface of this layer is 642 feet observed at sounding point R7. No indication of dissolution features exists.

#### 5.1.3 Integration and Discussion of Results

Overall, the seismic refraction and resistivity surveys complement and confirm each other. The bedrock profile derived from the two surveys is similar with an elevation difference of only 12 feet for the deepest segment. The correlation of near-surface layers is not as consistent, but this is understandable because the resistivity survey responds to water content while the seismic refraction survey responds to density. The seemingly more detailed profile derived from the seismic refraction data is due mainly to data density.

An explanation of the velocity increase in seismic Layer 2 at inline coordinate 970 feet is provided by the VES profile. Note that east of this point, VES Layers 2 and 3 are approximately the same thickness with VES Layer 2 pinching out to the west. Further to the west, when VES Layer 2 reappears in the section, it is always much thinner than VES Layer 3. This behavior suggests that the seismic refraction data interpretation is lumping VES Layers 2 and 3 into seismic Layer 2. Since the difference in velocity is small between dry and saturated clay

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(2,100 ft/sec), the refraction survey will indicate a combined layer velocity biased toward the thicker layer. This phenomenon is known as the hidden layer effect and is discussed in the Phase I Report. Actually, the velocity increase for seismic Layer 2 is more abrupt than indicated in Section 5.1.1 and occurs within 500 feet west of inline coordinate 970 feet. The more gradual change mentioned previously is necessary to prevent undesirable side effects and divergence in program FSIP.

Comparison of the geophysical results can be made using data from USATHAMA Borings 1, 9, 11, and 12 which are located on the south side of the Northern Perimeter Road from Line NP-1. Note that information from these borings was used after the geophysical data evaluation and then only to correlate and compare local stratigraphy and hydrology with the geophysical profiles. Also note that no correction has been made for ground surface elevation differences between the boring sites and the geophysical test sites because the borings were not surveyed as of this report date. Boring 12 at inline coordinate 382 feet indicates a near-surface silty clay layer about 12 feet thick with the water table at a depth of 62.6 feet and drilling refusal at a depth of 63.5 feet. Both the seismic and resistivity surveys show a near surface layer approximately 5 to 7 feet thick with the resistivity data indicating water at a depth of about 25 feet and the seismic data showing bedrock at a depth of about 57 feet. The only significant difference between the geophysics data and the drilling data is in the depth to the water table. It is possible that the borehole water level had not stabilized when the water level was determined because of the effects of the low permeability of the clay.

Boring 11 at inline coordinate 972 feet shows an essentially uniform section with the water level at a depth of 32.7 feet and drilling refusal at 44.8 feet. Both the seismic and resistivity data indicate a near-surface layer 3 to 5 feet thick with the resistivity data indicating water at a depth of about 5 feet and the seismic data indicating bedrock at a depth of about 45 feet. Again, the only difference is in the water level depth and the comments of the preceding paragraph apply here.

IDENTIFICATION

Boring 9 at inline coordinate 1958 shows a near-surface very-silty clay layer about 2 feet thick with the water level at a depth of 8.0 feet and drilling refusal at a depth of 32.3 feet. Both the seismic and resistivity data show a thin near-surface layer varying between 2 and 4 feet thick with the resistivity data showing water at a depth of about 7 feet and the seismic data indicating bedrock at about 42 feet. The difference in bedrock depth may be caused by the auger contacting a boulder or pinnacle during the drilling operation.

Boring 1 at inline coordinate 2,957 feet indicates a near-surface silt to silty-clay layer about 12 feet thick with the water level at a depth of 34.6 feet and drilling refusal at 51.8 feet. The seismic data indicate a near-surface layer about 8 feet thick with bedrock at a depth of about 97 feet. The resistivity data indicate the water level at a depth of about 28 feet. As discussed above, the difference in bedrock depth may be caused by the auger contacting a boulder or pinnacle. The boring log indicates "soft, wet auger returns" at a depth of 23.6 feet so that the slight difference in water level is most likely caused by lack of water level stabilization as the water level measurement was made on the same day that the borehole was drilled.

## 5.2 NEW ACID AREA

### 5.2.1 Seismic Refraction Results

The New Acid Area seismic refraction survey results are shown in Figure 4. The estimated resolving power of the seismic refraction survey permits detection of features as small as 15 feet in size. Layer depths are believed to be accurate to within ten percent. The abscissa is the station number and the ordinate is MSL elevation in feet. There are 15 feet between stations. VAAP coordinates for all New Acid Area seismic lines are listed in Table 3. Three distinct layers are indicated and are described below in order from top to bottom.

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Layer 1 has a velocity of 1,720 ft/sec and is interpreted to be a thin layer of relatively loose and uncompacted clays, silts, and chert fragments with a maximum thickness of about 15 feet. This layer thickens toward the northwest end of lines NAS-2 and NAS-3 and toward the southwest end of Lines NAS-5 and NAS-6. This layer is similar to seismic Layer 1 along the Northern Perimeter Road. The slight difference in velocities is not significant.

Layer 2 has a velocity of 3,550 ft/sec and is interpreted to consist of slightly moist clays. This layer thickens toward the northwest end of Lines NAS-1, NAS-2, and NAS-3, toward the northeast end of Lines NAS-4 and NAS-5, and toward the southwest end of Line NAS-6. This layer is similar to seismic Layer 2 in the easternmost portion of the Northern Perimeter Road. The slight difference in velocities is not significant.

Layer 3 has a velocity of 17,700 ft/sec and is interpreted on the basis of local geology to be carbonate bedrock. The bedrock surface dips to the northwest. Note the depression in the bedrock surface at Station 6, Line NAS-6 near a known sinkhole beneath the D-402 soda ash tank. Similar depressions are seen on Lines NAS-2, NAS-3, NAS-4, and NAS-5. The lowest bedrock elevation indicated is about 738 feet at Station 23, Line NAS-4. This layer is similar to seismic Layer 3 along the Northern Perimeter Road. The difference in velocities may indicate less intense weathering in the New Acid Area.

A structural map of the top of Layer 2 based on the seismic refraction data (Layer 1/Layer 2 interface) is presented in Figure 5. The surface is smooth with only 5 to 10 feet of relief across the site. The predominant trend is a deepening of Layer 2 (thickening of Layer 1 since the site is essentially flat) along a southeast-northwest axis through the center of the site.

A structural map of the bedrock surface based on seismic refraction data (top of Layer 3) is presented in Figure 6. There appears to be considerable structure present with up to 35 feet of relief across the site.

The most predominant trend is a linear depression aligned on a southeast-northwest axis through the center of the site. It is likely that the linear depression represents a dissolution system. Removal of material by groundwater flow near the bedrock surface could induce subsidence in the upper soil layers as can be seen in Layer 2. This is shown in Figure 5. A slight, isolated rise is apparent toward the center of Line NAS-4.

#### 5.2.2 Vertical Electrical Sounding Results

The results of the VES in the New Acid Area are shown in Figure 7. Layer depths are believed to be accurate to within 20 percent. VAAP coordinates of all VES points in the New Acid Area are presented in Table 4. Displayed in Figure 7 are two lines of cross section through the respective soundings with the MSL elevation shown on the ordinate. Data from VES-3, VES-4, VES-5, VES-6, VES-7, VES-9, VES-10, VES-11, and VES-12 yielded best fit models with four layers. Data from VES-1, VES-2, and VES-8 yielded similar models but did not detect the top of the fourth layer due to unavoidable and perturbing effects of metal pipes. The four layers are discussed in order from top to bottom.

Layer 1 is a thin layer immediately beneath the surface with a mean resistivity of 290 ohm-meters. This layer is interpreted to be composed of relatively loose and uncompacted clays, silts, and chert fragments that were saturated by heavy rainfall just prior to commencement of the field program. This layer attains a maximum thickness of about 5 feet at VES-4 and is considered to be equivalent to VES Layer 1 along the Northern Perimeter Road.

Layer 2 varies in thickness from 6 to 33 feet and has a mean resistivity of 1,350 ohm-meters. This layer thickens rapidly at VES-7 and VES-8. Layer 2 is interpreted to consist mainly of dry to slightly moist clays and chert fragments. Layer 2 is considered to be similar to VES Layer 2 along the Northern Perimeter Road, but is believed to have lower water content because of its higher resistivity.

IDENTIFICATION

Layer 3 varies in thickness from 38 feet at VES-7 to 76 feet at VES-10 and has a mean resistivity of 380 ohm-meters. The top surface of Layer 3 has a maximum elevation of about 810 feet at VES-1 and a minimum elevation of about 780 feet at VES-8. This layer is interpreted to represent a zone of moist to partially-saturated clays and is similar to VES Layer 3 along the Northern Perimeter Road although the water content is lower as evidenced by significantly higher resistivity.

The mean resistivity of Layer 4 is 670 ohm-meters and this layer indicates carbonate bedrock. The lowest elevation for the top of this layer is about 731 feet at VES-10.

### 5.2.3 Horizontal Profiling Resistivity Results

The HP survey results are presented in Figure 8. VAAP coordinates for both HP lines are presented in Table 5. The abscissa is the station number with 30 feet between stations and the ordinate on the right side is MSL elevation in feet. The ordinate on the left side is "N factor" which is a convenience used when plotting the data and is related to the dipole separation distance. Station 1 on both lines corresponds to Row 1 of the New Acid Area grid. The numbers on the cross-sections indicate apparent resistivity values in units of 100 ohm-meters.

Line NAR-2 shows fairly constant resistivity values (270-500 ohm-meters) to the southeast of Station 12. These values are characteristics of VES Layer 3 as discussed in Section 5.2.2. The small variations in resistivity indicate slight changes in the thicknesses of VES Layers 1 and 2. The increase in resistivity to the northwest of Station 12 is attributed to a significant thickening of VES Layer 2 as shown by sounding VES-8. No indication of bedrock is apparent.

Line NAR-3 shows fairly constant resistivity values (320-470 ohm-meters) to the southeast of Station 6. As previously mentioned, these values are characteristic of VES Layer 3. The increasing resistivity to the northwest of Station 6 is characteristic of the increasing thickness of

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VES Layer 2. The slight drop in resistivity values to the northwest of Station 13 is attributed to slight thickening of VES Layer 1. No indication of bedrock is apparent.

#### 5.2.4 Gravity Results

Two figures are included to illustrate the gravity results. The estimated accuracy of the gravity survey is to within plus or minus 0.016 milligals. Figure 9 is a Bouguer anomaly map which represents the gravity values corrected for elevation, tides, and temporal drift. The contours are in units of 0.01 milligals and show a strong decrease to the northwest. This behavior indicates a bedrock surface which dips in this direction. The gradient is steepest in those areas where the seismic bedrock map (Figure 6) shows the greatest dips.

Figure 10 shows the same data with the strong decreasing trend to the northwest removed. In other words, Figure 10 shows the residual gravity anomaly that would exist if the bedrock was rotated to an approximately horizontal position. Note that a linear gravity low still exists with the axis aligned roughly along Column K. This low is attributed to the previously mentioned "trough" on the bedrock surface. Also note the significant low-gravity anomaly that occurs near Column P, Row 15. This anomaly has the characteristics of a spherical body. The depth to the center of the body can be estimated from half-width considerations. The intensity of the anomaly decreases to roughly one-half over a distance of 30 feet. The depth to the anomaly is equal to this distance divided by 0.77 which yields a depth of about 40 feet. Two models can be used to explain the anomaly. The first model is a spherical water-filled cavity in the clay overburden with a radius of 22 feet and a depth to the top of the sphere of 18 feet. The second model is a spherical air-filled cavity in the clay overburden with a radius of 17 feet and a depth to the top of the sphere of 23 feet. It is cautioned that these results are preliminary and based on initial reconnaissance surveys. Additional data is needed to substantiate these models. The known sink-hole beneath the D-402 soda ash tank is not indicated by the gravity

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data. This is to be expected because prior to the gravity survey, the sinkhole was back filled with crushed limestone which effectively removes the density contrast.

#### 5.2.5 Integration and Discussion of Results

The seismic refraction, VES resistivity, and gravity surveys complement and confirm the results of each other. The trough-like feature apparent on Figure 6 (seismic bedrock map) is apparent on both the VES profiles (Figure 7) and the gravity map (Figures 9 and 10). As mentioned previously, it is likely that the trough-like feature represents a dissolution system. The bedrock elevations on the southwest-northeast VES profile agree with the elevations on the seismic bedrock map to within 5 feet. The bedrock elevations on the northwest-southeast VES profile diverge to a greater degree with the minimum bedrock elevation being 731 feet at VES-10 versus 745 feet for the seismic refraction at the same point.

When VES Layers 1 and 2 are combined, they correlate with seismic Layer 1 except at VES-7 and VES-8 where the resistivity data show rapid thickening. Some discrepancy is to be expected, however, since the two techniques are measuring different properties. VES Layer 3 is correlated with seismic Layer 2. While this layer is interpreted to be a zone of partially-saturated clays, there is no evidence to indicate that it represents the water table. In fact, based on the resistivity survey, no water table is apparent in the New Acid Area to a depth of 85 feet. The absence of the water table above this depth is confirmed by foundation investigation borings drilled in 1969 and 1971 by the U.S. Army Corps of Engineers.

The gravity low at Column P, Row 15, which has the characteristics of a spherical cavity in the overburden, is not confirmed by the seismic refraction or resistivity surveys as there is no coverage in this area.

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The results of the HP resistivity survey are not considered particularly useful. While it is possible to interpret the results using information supplied from the other geophysical techniques, the HP technique did not provide any additional or unique information. A limitation with the HP technique is that it is extremely difficult to invert the data in a rigorous fashion and the pseudo-section approach has very limited capability.

Comparison can be made between the seismic refraction data results and data from borings drilled by the U.S. Army Corps of Engineers as part of the foundation analysis for the New Acid Area. The boring data were provided by the operating staff at VAAP. Note that information from these borings was used after the geophysical data evaluation and then only to correlate and compare local stratigraphy and hydrology with the geophysical profiles. Boring SS-1-71 is located at Station 1 of Line NAS-6 on the southwest corner of the D-402 soda ash tank. This boring shows a 9-foot-thick near-surface layer of sandy clay that correlates well with the 10-foot-thick seismic Layer 1. The observed bedrock depth in the boring was 42.4 feet which agrees closely with the depth of 47 feet determined by the seismic refraction survey.

Borings SS-4-71, SS-5-71, and SS-6-71 are located on the north side of the D-402 tank between Stations 3 and 5 of Line NAS-1. These borings show a highly irregular bedrock surface with depths ranging from 29 to 39 feet. A cavity was detected in Boring SS-6-71 at a depth of 32 to 38 feet. The depth to bedrock determined from the seismic refraction survey in this area varies from 46 to 49 feet. It is highly probable that the seismic data represents a more competent bedrock surface with the resulting greater depth.

Borings D-1-69, D-4-69, and D-7-69 are located along the northern edge of SAR #1 Battery. Bedrock was contacted at Elevation 764 feet in Boring D-1-69. The remaining two borings were drilled to Elevation 759 feet and 758 feet respectively without contacting bedrock. The bedrock

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elevation as determined from the seismic refraction survey in this area is varying between 755 and 760 feet which correlates well with Boring D-1-69 and, to the depths drilled, is consistent with the information from the other two borings.

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in borings and the presence of rock pinnacles and boulders in the overburden. Note that information from borings was used after the geophysical data evaluation and then only to correlate and compare local stratigraphy and hydrology with the geophysical profiles. The fourth geophysical technique, HP resistivity, is judged to be ineffective due to the limited amount of additional information gained by the technique. The HP resistivity results can, however, be interpreted in a manner consistent with the results of the other surveys.

Overall, VES resistivity appears to be the most effective technique tested at VAAP. With this technique, both the water table (where present) and the bedrock surface were easily detected. Seismic refraction is judged to be nearly as effective. Although delineation of the water table was hampered by hidden layer effects at the Northern Perimeter site, seismic refraction offers compensation in the form of better lateral resolution along the bedrock surface which provided an indication of dissolution features.

## 6.2 RECOMMENDATIONS

### 6.2.1 Seismic Refraction

The seismic refraction procedure used at VAAP was entirely adequate. However, in areas where the bedrock exceeds a depth of about 100 feet, it is recommended that a more powerful source such as multiple synchronized Betsy Seisguns or small explosive charges in shallow holes be used to provide more source energy. Additionally, it is recommended that a parallel and separate velocity survey be performed to provide additional velocity data. The best means of obtaining this information would be a cross-hole seismic survey. Continuous velocity logging is also attractive, but is generally ineffective in material where the velocity is less than about 5,000 ft/sec.

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#### 6.2.2 VES Resistivity

The VES resistivity procedure used at VAAP was appropriate. Care should be exercised, however, to avoid buried metal pipes and steel fences. This requirement can limit the applicability of the VES method in developed areas. Continuous resistivity logging in open boreholes would provide information which would reduce interpretation time by restricting the possible range of subsurface models.

#### 6.2.3 HP Resistivity

The HP resistivity used at VAAP was entirely adequate, but difficulties in interpretation do exist. It is recommended that VES resistivity procedures be used instead.

#### 6.2.4 Gravity

The gravity procedure used at VAAP was appropriate. Continuous density logging would permit more quantitative interpretation of the gravity data.

#### 6.2.5 Additional Techniques

While the geophysical techniques employed at VAAP were selected because they were judged to have the highest probability of success based on site conditions, it is recognized that various additional geophysical techniques may be applicable. Specifically, these additional techniques are:

- Audio magneto-telluric (AMT) resistivity
- Electromagnetics
- Ground-probing radar

Both AMT resistivity and electromagnetics could be used to furnish the same information as electrical resistivity and might be less sensitive to perturbations from metallic pipes and fences. Ground-probing radar would provide an excellent method for delineating solution features provided that the depth is less than approximately 30 feet. Additionally, radar would be useful for mapping shallow water tables such as the one encountered in the topographically low areas of the Northern Perimeter site.

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### 6.3 COMMENTS

Although the timing between field operations and evaluated data output was on the order of months due to scheduling and the experimental nature of the project, it is anticipated that future "routine-type" geophysical surveys could be conducted and interpreted in a matter of a few weeks. When necessary, it is entirely feasible to perform a simple interpretation of data in the field in a matter of days. Such an interpretation was actually performed in the field at VAAP on representative data sets from each geophysical technique tested to ensure proper field procedure.

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TABLES

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TABLE 1  
NORTHERN PERIMETER ROAD SITE  
VAAP COORDINATES FOR SEISMIC LINE NP-1 ENDPOINTS

END	NORTH COORDINATE <sup>(1)</sup> (ft)	EAST COORDINATE <sup>(1)</sup> (ft)	MSL ELEVATION <sup>(2)</sup> (ft)
East	62,007.0	54,756.9	750.7
West	60,407.4	51,580.3	757.9

(1) VAAP plant grid.

(2) National Geodetic Vertical Datum of 1929.

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NORTHERN PERIMETER ROAD SITE  
VAAP COORDINATES FOR VES SOUNDINGS

SOUNDING	NORTH COORDINATE <sup>(1)</sup> (ft)	EAST COORDINATE <sup>(1)</sup> (ft)	MSL ELEVATION <sup>(2)</sup> (ft)
R1	62,007.0	54,756.9	750.7
R2	61,804.1	54,412.6	727.6
R3	61,603.9	54,064.8	723.5
R4	61,461.4	53,663.6	702.9
R5	61,385.0	53,295.8	695.0
R6	61,221.1	52,970.4	702.0
R7	61,063.3	52,551.2	715.6
R8	60,886.4	52,210.8	736.8
R9	60,680.2	51,866.9	752.8
R10	60,427.5	51,618.7	753.3
R11	62,074.2	54,723.9	755.7
R12	60,747.1	52,320.5	720.8

(1) VAAP plant grid.

(2) National Geodetic Vertical Datum of 1929.

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TABLE 3  
NEW ACID AREA SITE  
VAAP COORDINATES FOR SEISMIC LINE ENDPOINTS

LINE/STATION	NORTH COORDINATE <sup>(1)</sup> (ft)	EAST COORDINATE <sup>(1)</sup> (ft)	MSL ELEVATION <sup>(2)</sup> (ft)
NAS-1/1	61,252.8	56,550.4	818.2
NAS-1/12	61,292.3	56,388.9	817.8
NAS-2/1	61,406.5	56,555.0	818.6
NAS-2/23	61,484.8	56,232.4	815.6
NAS-3/1	61,611.0	56,603.6	818.6
NAS-3/23	61,690.4	56,281.1	814.3
NAS-4/1	61,332.2	56,102.1	813.7
NAS-4/23	61,652.5	56,179.2	813.3
NAS-5/1	61,273.5	56,338.6	817.4
NAS-5/23	61,595.3	56,413.0	816.7
NAS-6/1	61,238.2	56,485.9	818.3
NAS-6/23	61,558.9	56,562.3	818.3

(1) VAAP plant grid.

(2) National Geodetic Vertical Datum of 1929.

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TABLE 4  
NEW ACID AREA SITE  
VAAP COORDINATES FOR VES SOUNDINGS

SOUNDING	NORTH COORDINATE <sup>(1)</sup> (ft)	EAST COORDINATE <sup>(1)</sup> (ft)	MSL ELEVATION <sup>(2)</sup> (ft)
VES-1	61,375.6	56,300.2	816.6
VES-2	61,434.4	56,314.3	816.6
VES-3	61,491.7	56,327.6	816.7
VES-4	61,550.9	56,340.8	816.1
VES-5	61,609.9	56,354.4	816.0
VES-6	61,668.7	56,368.1	815.7
VES-7	61,719.6	56,378.5	815.2
VES-8	61,593.2	56,165.3	813.8
VES-9	61,609.1	56,231.0	814.2
VES-10	61,594.4	56,288.9	815.2
VES-11	61,555.7	56,406.0	816.6
VES-12	61,551.4	56,466.2	817.7

(1) VAAP plant grid.

(2) National Geodetic Vertical Datum of 1929.

ID: A1P1010N1A

TABLE 5  
NEW ACID AREA SITE  
VAAP COORDINATES FOR HP RESISTIVITY LINE ENDPOINTS

LINE/STATION	NORTH COORDINATE <sup>(1)</sup> (ft)	EAST COORDINATE <sup>(1)</sup> (ft)	MSL ELEVATION <sup>(2)</sup> (ft)
NAR-2/1	61,505.0	56,144.7	814.2
NAR-2/18	61,510.6	56,115.8	814.2
NAR-3/1	61,597.0	56,661.5	817.4
NAR-3/18	61,717.7	56,163.2	812.8

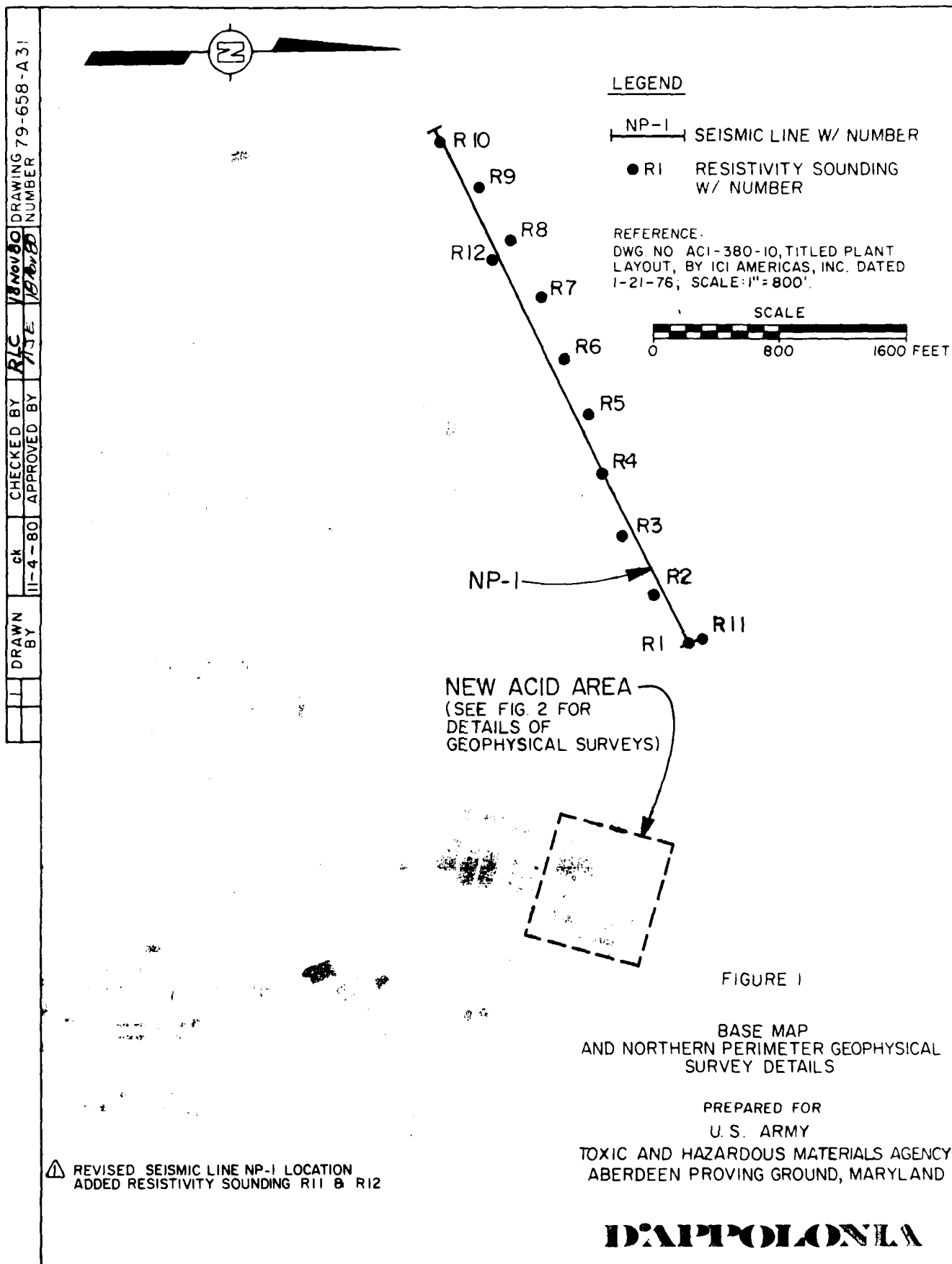
(1) VAAP plant grid.

(2) National Geodetic Vertical Datum of 1929.

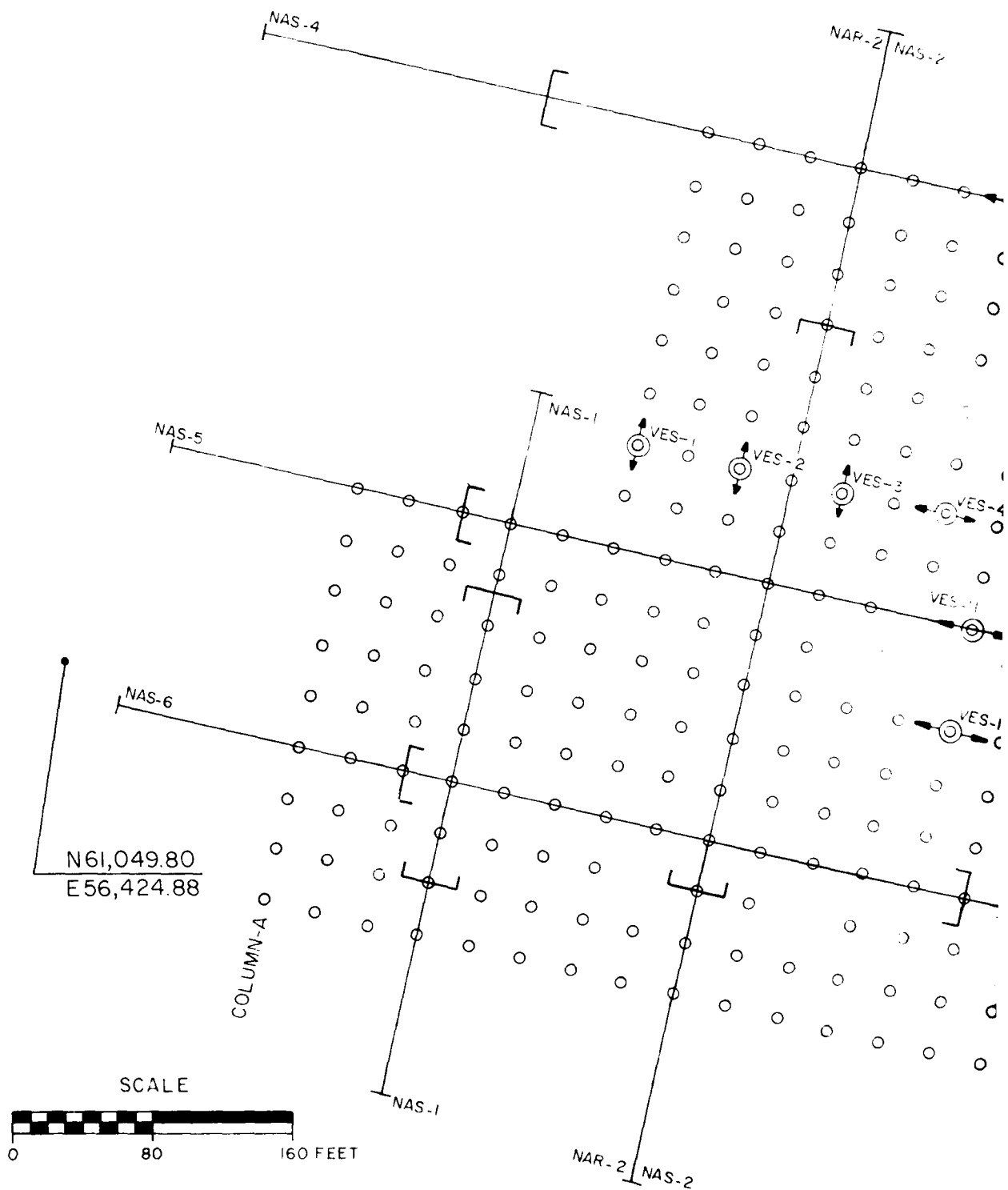
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FIGURES

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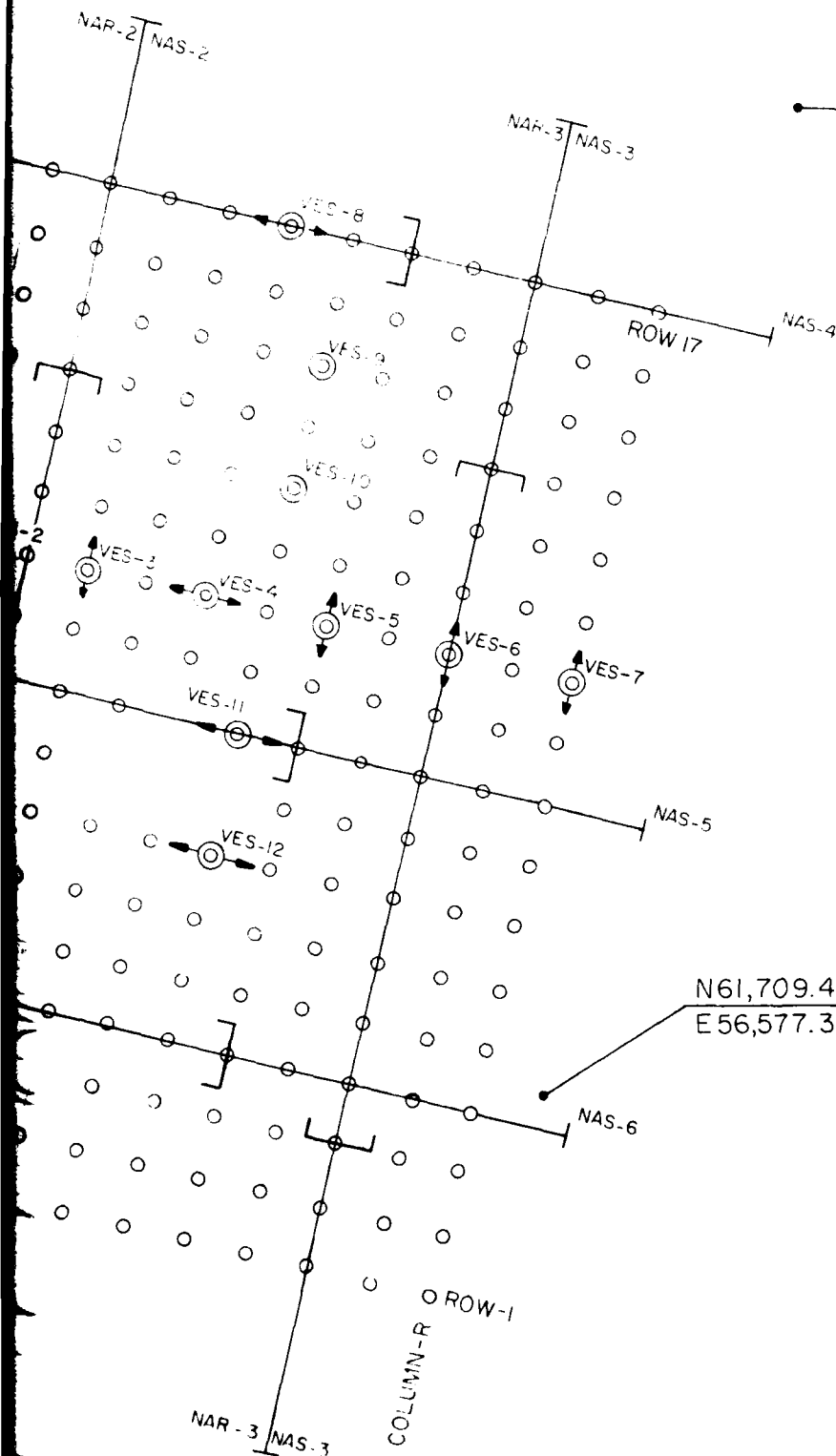
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		11-6-80	APPROVED BY	AJE	18 NOV 80		





# REFERENCE

DWG NO. ACI-P-1040-4, TITLED PLOT PLAN  
NEW ACID AREA, BY ATLAS CHEMICAL  
INDUSTRIES, INC. DATED 3-10-71; SCALE  
1"=50'



N61,826.61  
E 56,106.56

## LEGEND

- SEISMIC REFRACTION LINE
- HORIZONTAL PROFILING RESISTIVITY LINE
- GRAVITY MEASURING POINT
- VES-7  
VERTICAL ELECTRICAL SOUNDING POINT
- INDICATES LIMITS OF SUBSURFACE SEISMIC COVERAGE

## NOTES

- 1 SYMBOLS SHOWN IN LEGEND ARE SUPERIMPOSED AT THOSE POINTS WHERE MORE THAN ONE GEOPHYSICAL TECHNIQUE WILL BE EMPLOYED.
- 2 ARROWS ON VERTICAL ELECTRICAL SOUNDING POINTS INDICATE DIRECTION OF ELECTRODE EXPANSION.

FIGURE 2

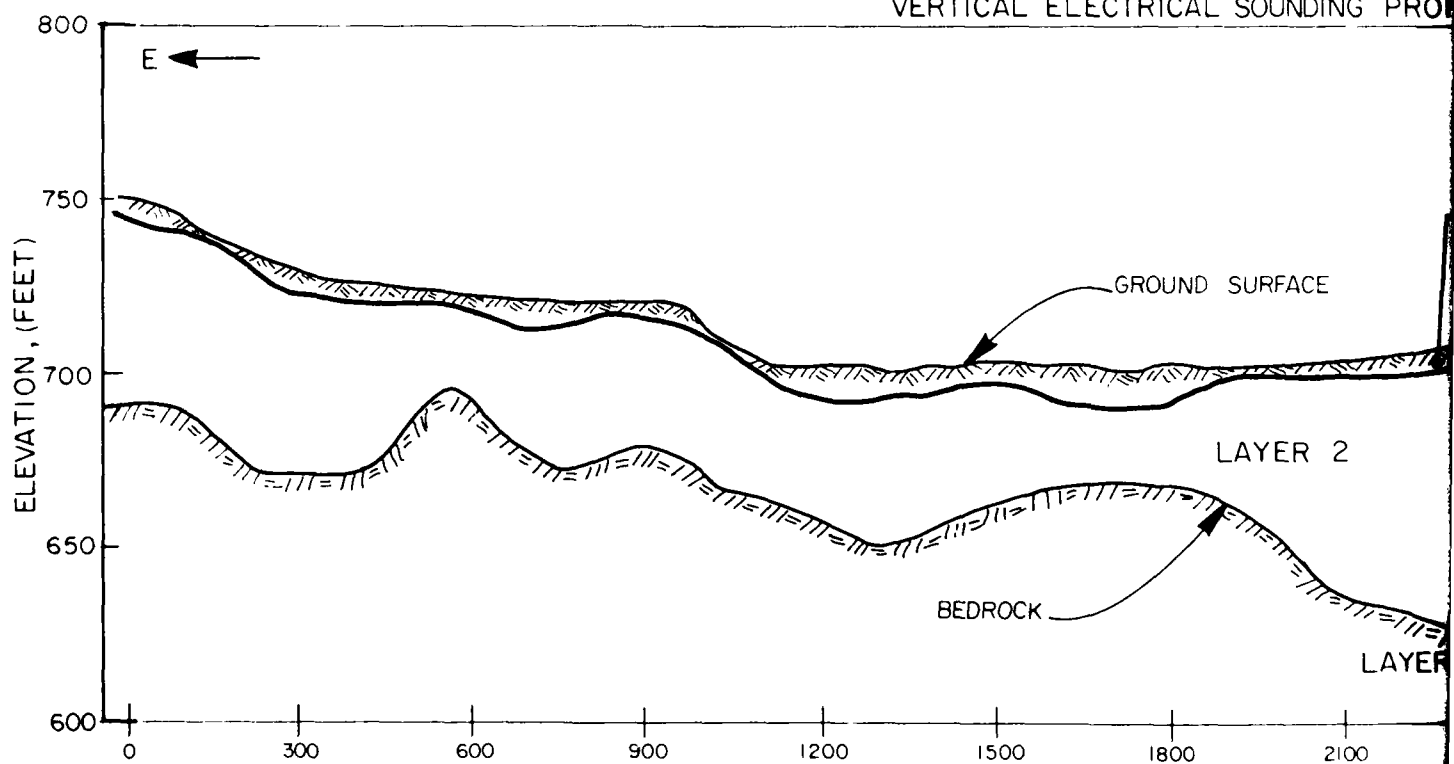
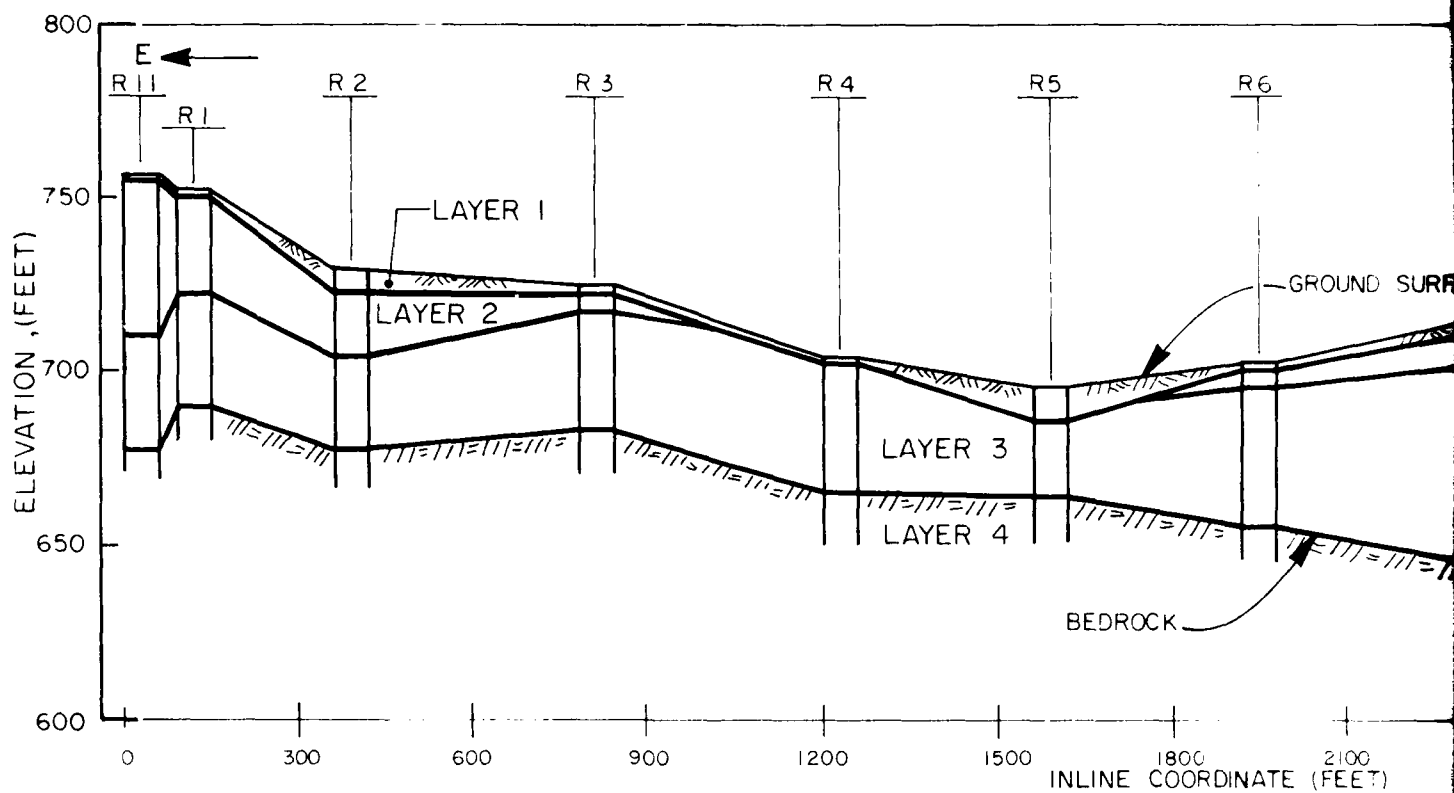
NEW ACID AREA  
GEOPHYSICAL SURVEY DETAILS

PREPARED FOR  
U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

DD FORM 100-10-1



DRAWN BY  
 JUL 8-27-81  
 CHECKED BY  
 APPROVED BY  
 RLC  
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 ZSEP 81  
 DRAWING NUMBER  
 79-658-B3

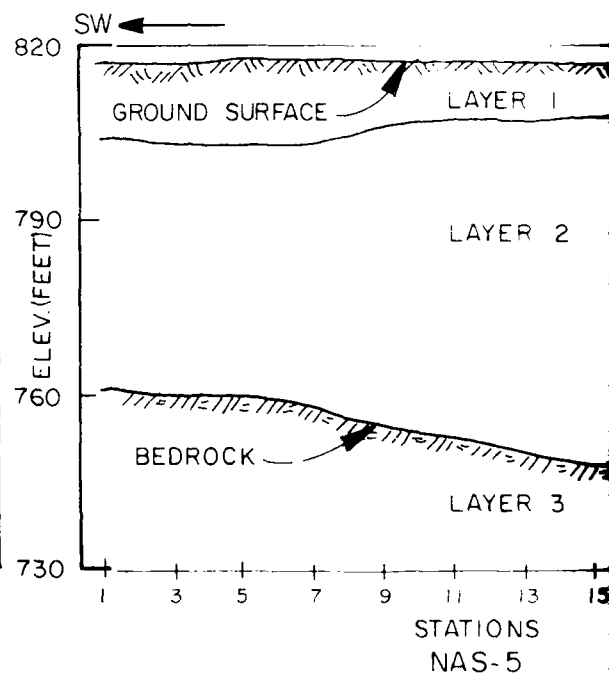
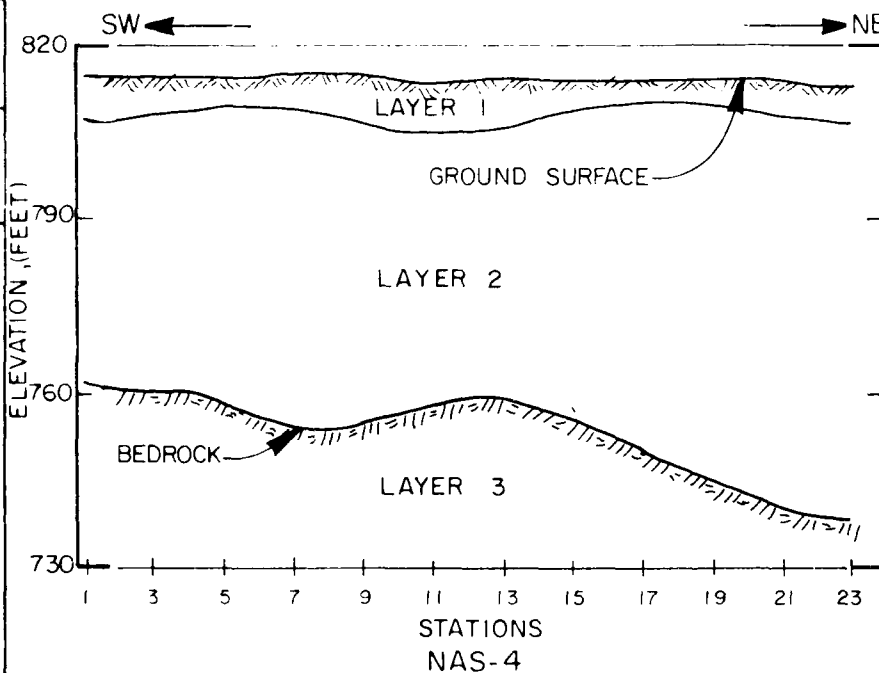
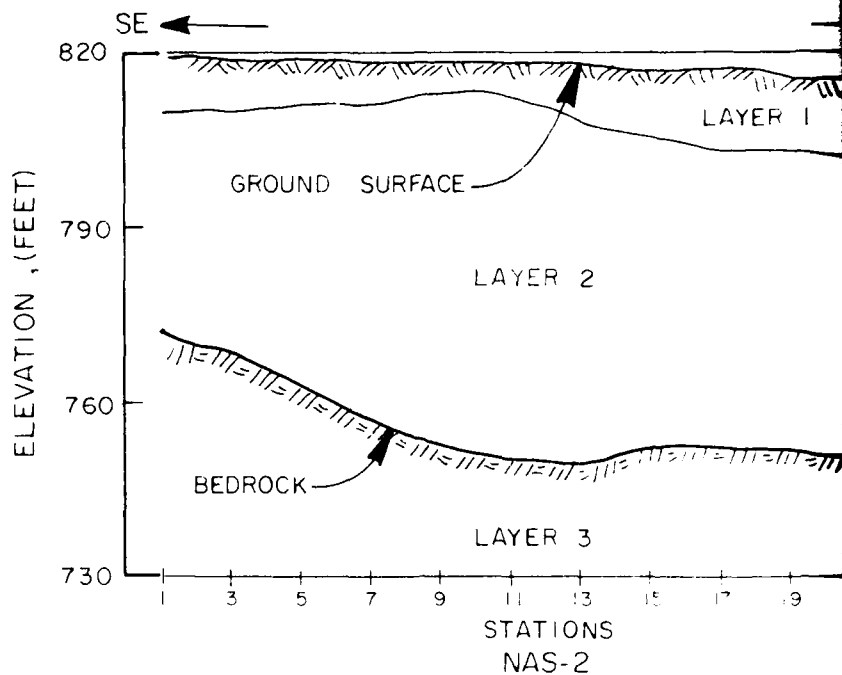
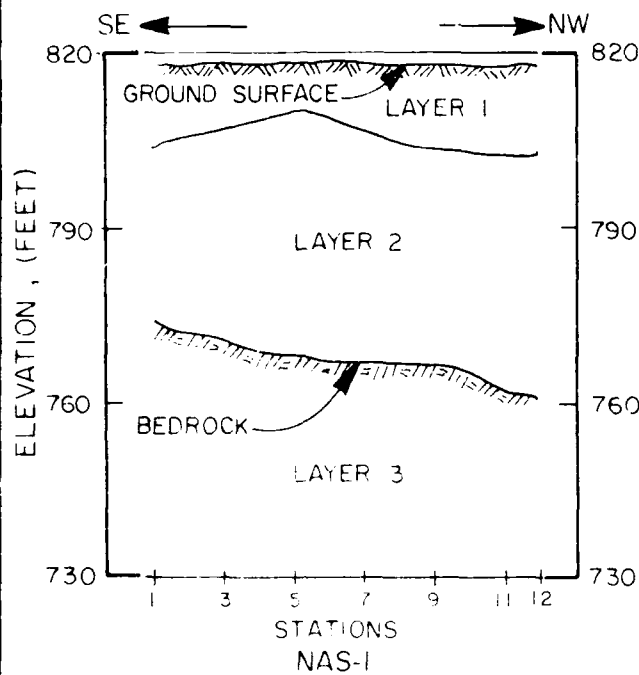


NOTES:

1. ELEVATIONS ARE MSL
2. SEE TEXT FOR RESISTIVITY AND VELOCITY VALUES
3. VERTICAL EXAGGERATION EQUALS 1.5
4. VES SOUNDINGS R1, R4, R10 ON SEISMIC LINE-OTHERS PROJECTED



DRAWING 79-658-B4  
 25 SEP 81  
 25 SEP 81  
 R/S  
 8-28-81  
 CHECKED BY  
 APPROVED BY  
 J.J.L.  
 DRAWN BY



NOTES:

1. STATION SPACING EQUALS 15 FEET
2. VERTICAL EXAGGERATION EQUALS 2.5
3. LAYER 1 VELOCITY EQUALS 1720 F/S
4. LAYER 2 VELOCITY EQUALS 3550 F/S
5. LAYER 3 VELOCITY EQUALS 17,700 F/S
6. ELEVATIONS ARE MSL

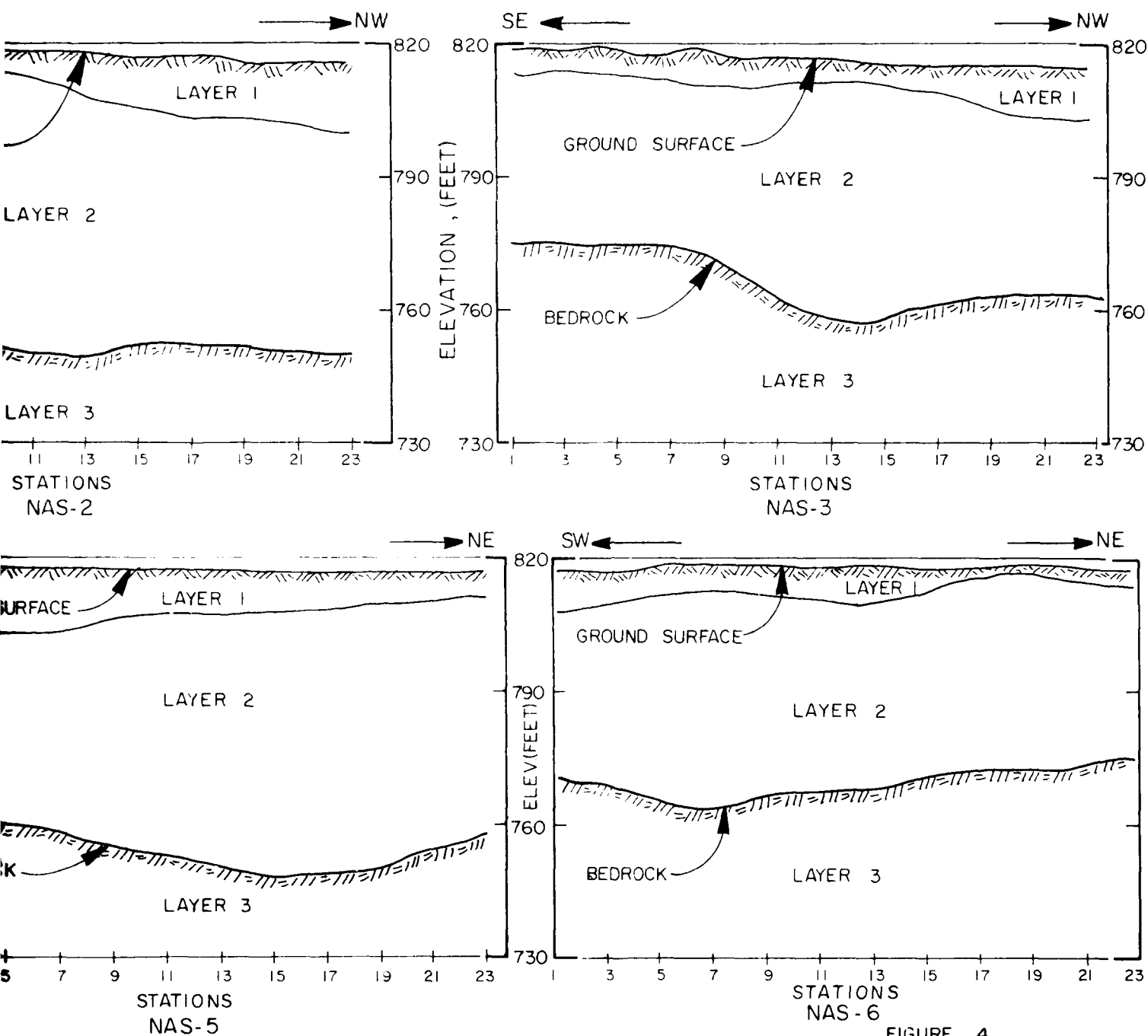


FIGURE 4  
NEW ACID AREA  
SEISMIC REFRACTION PROFILES

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U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

DD FORM 100-1

25 SEP 81  
DRAWING 79-658-B6  
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BY

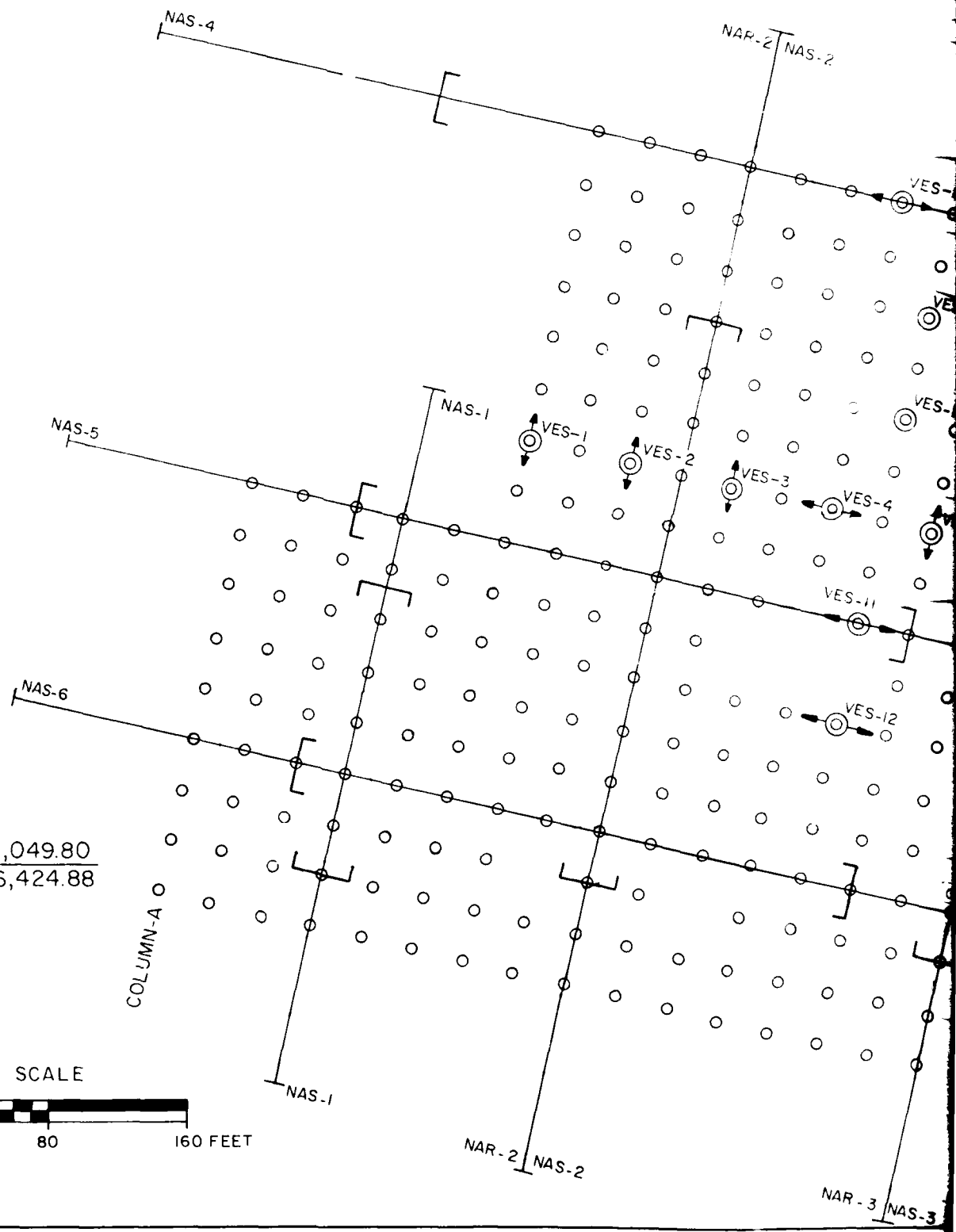
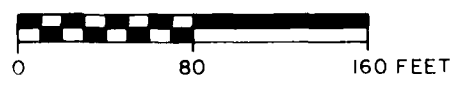
5

4

N61,049.80  
E 56,424.88

COLUMN-A

SCALE





DWG. NO ACI-P-1040-4, TITLED PLOT PLAN  
NEW ACID AREA, BY ATLAS CHEMICAL  
INDUSTRIES, INC DATED 3-10-71; SCALE  
1"=50'.

N 61,826.61  
E 56,106.56

LEGEND

NAS-1 NAS-1 SEISMIC REFRACTION LINE

NAR-2 NAR-2

HORIZONTAL PROFILING  
RESISTIVITY LINE

O GRAVITY MEASURING POINT

VES-7      VERTICAL ELECTRICAL  
SEISMIC COVERAGE

 INDICATES LIMITS OF SUBSURFACE  
COVERAGE

NOTES:

- 1 SYMBOLS SHOWN IN LEGEND ARE SUPERIMPOSED AT THOSE POINTS WHERE MORE THAN ONE GEOPHYSICAL TECHNIQUE WILL BE EMPLOYED.
- 2 ARROWS ON VERTICAL ELECTRICAL SOUNDING POINTS INDICATE DIRECTION OF ELECTRODE EXPANSION.

FIGURE 5

NEW ACID AREA  
SEISMIC REFRACTION  
LAYER 2 STRUCTURAL MAP

PREPARED FOR

U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

# INDIANPOLAND

DRAWING 79-658-B5  
NUMBER

25 SEP 81

RLC

CHECKED BY

APPROVED BY

SH  
8-28-81

DRAWN  
BY

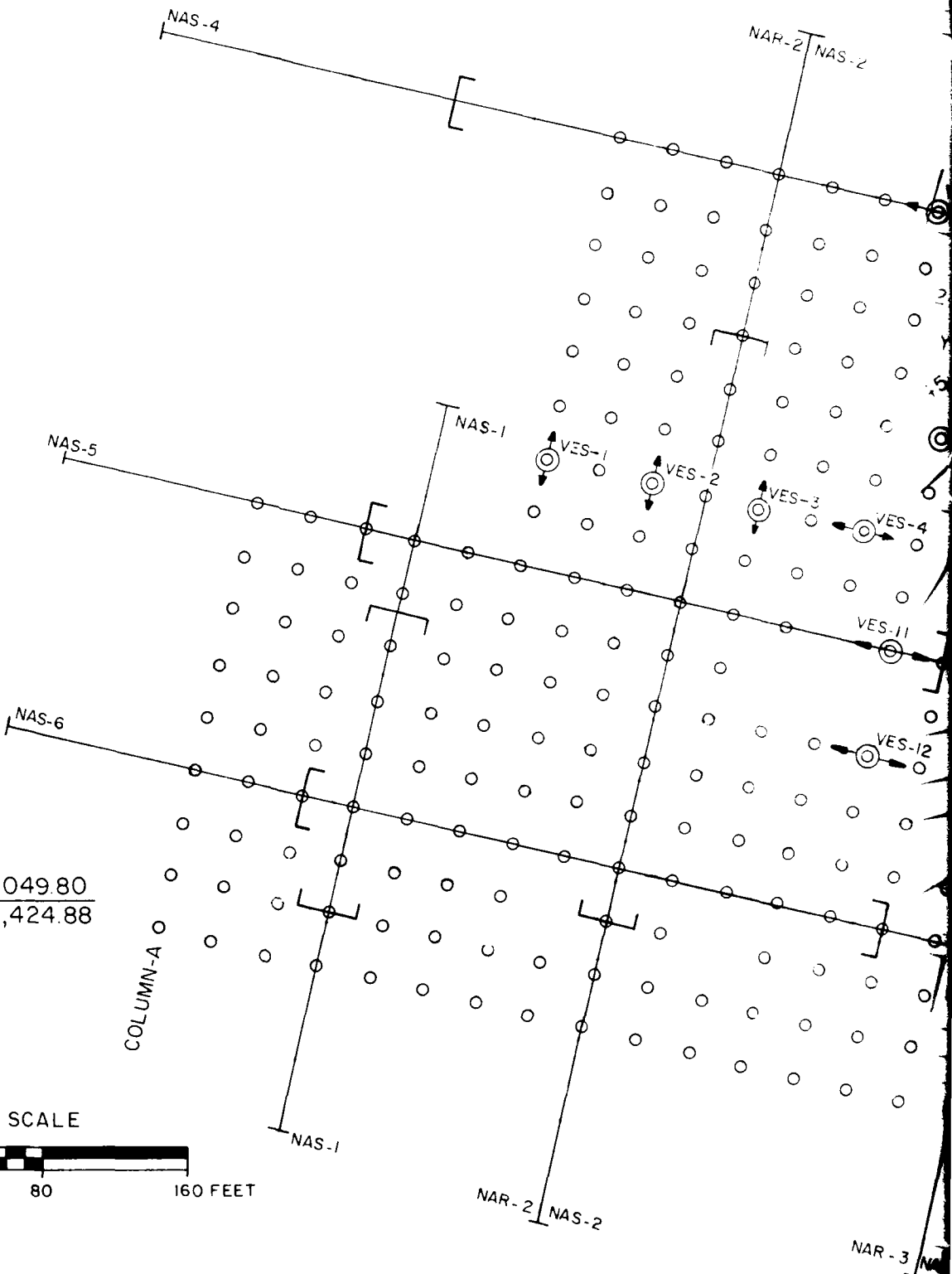
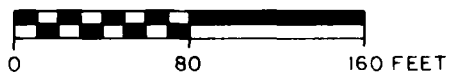
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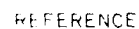
3

N61,049.80  
E 56,424.88

COLUMN-A

SCALE





DWG NO ACI-P-1040-4, TITLED PLOT PLAN  
NEW ACID AREA, BY ATLAS CHEMICAL  
INDUSTRIES, INC DATED 3-10-71; SCALE  
1"=50'

N 61,826.61  
E 56,106.56

LEGEND

NAS-1 NAS-1 SEISMIC REFRACTION LINE

NAR-2 NAR-2

HORIZONTAL PROFILING  
RESISTIVITY LINE

○ GRAVITY MEASURING POINT

VES-7      VERTICAL ELECTRICAL  
SOUNDING POINT

INDICATES LIMITS OF SUBSURFACE  
SEISMIC COVERAGE

NOTES:

1. SYMBOLS SHOWN IN LEGEND ARE SUPERIMPOSED AT THOSE POINTS WHERE MORE THAN ONE GEOPHYSICAL TECHNIQUE WILL BE EMPLOYED.
2. ARROWS ON VERTICAL ELECTRICAL SOUNDING POINTS INDICATE DIRECTION OF ELECTRODE EXPANSION.

FIGURE 6

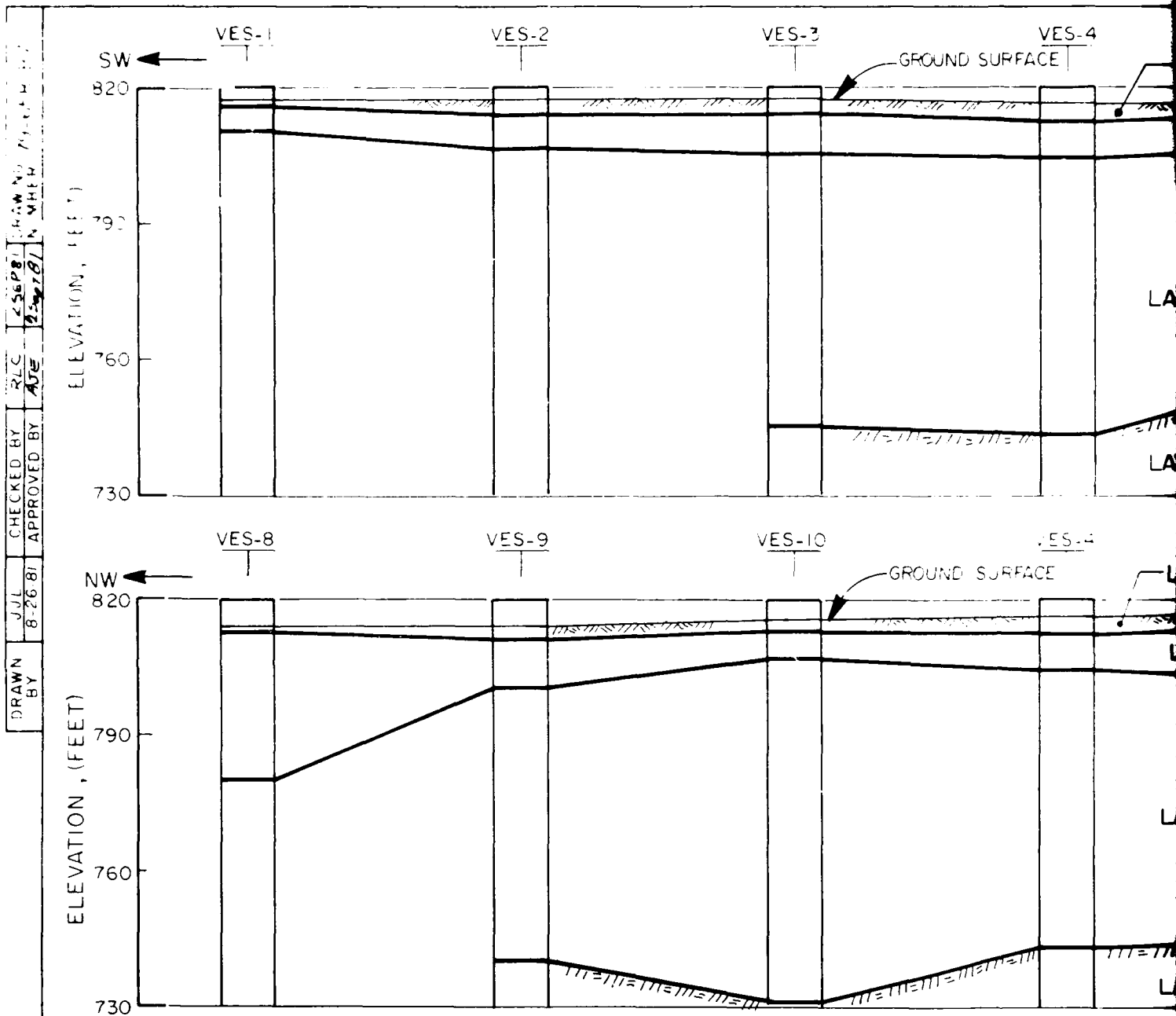
NEW ACID AREA  
SEISMIC REFRACTION  
BEDROCK STRUCTURAL MAP

PREPARED FOR

U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

# INDAPRODOLINA





NOTES:

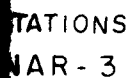
1. LAYER 4 NOT DETECTED AT VES-1, VES-2, VES-3.  
FOR EXPLANATION SEE TEXT.
2. LAYER 1 AVERAGE RESISTIVITY EQUALS 290 OHM-METERS
3. LAYER 2 AVERAGE RESISTIVITY EQUALS 1350 OHM-METERS
4. LAYER 3 AVERAGE RESISTIVITY EQUALS 380 OHM-METERS
5. LAYER 4 AVERAGE RESISTIVITY EQUALS 670 OHM-METERS
6. ELEVATIONS ARE MSL
7. NO VERTICAL EXAGGERATION



PREPARED FOR  
U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

# INDIANPOLONA

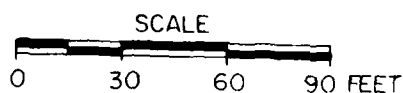
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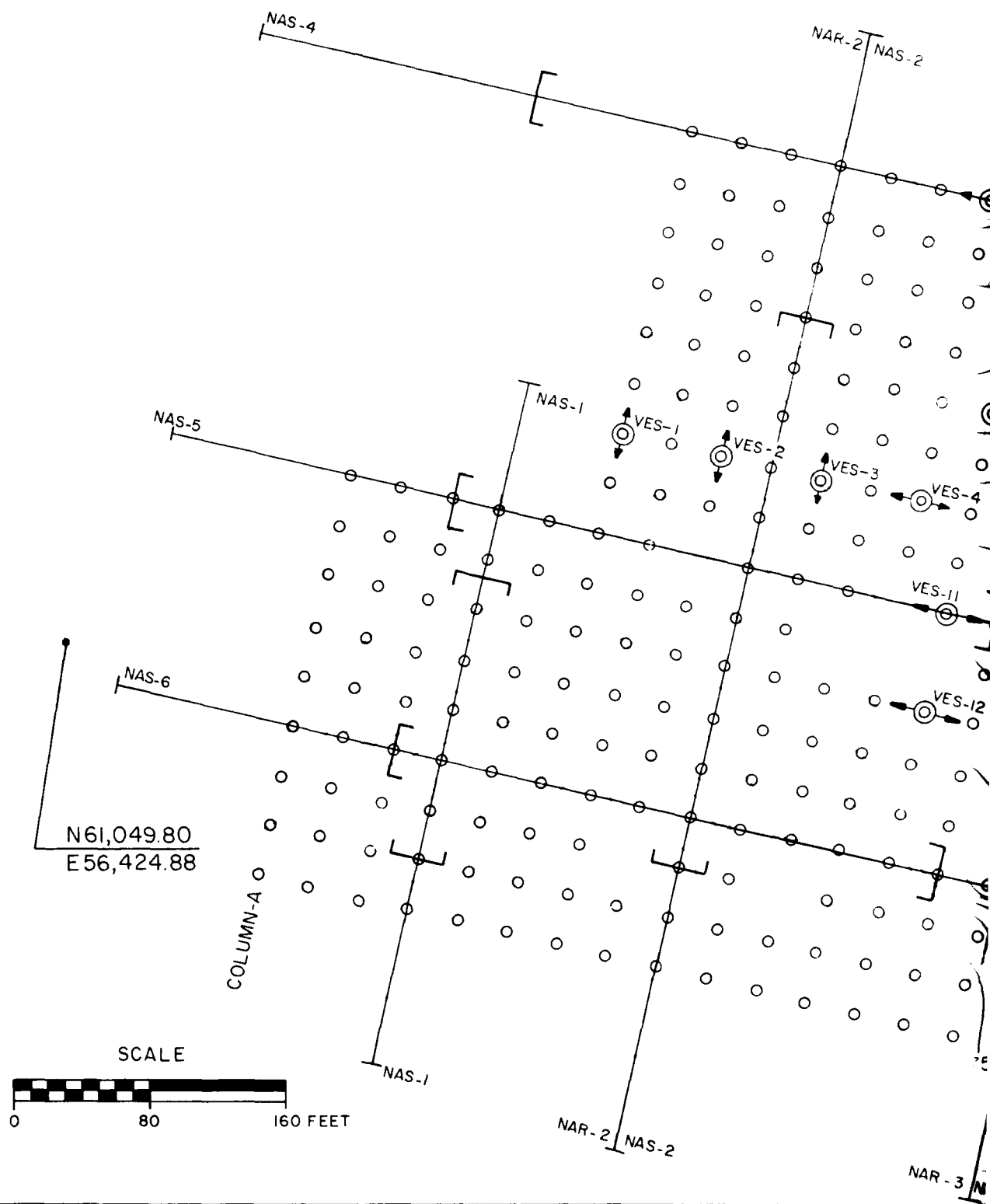
NEW ACID AREA  
HP RESISTIVITY PSEUDO-SECTIONS

U. S. ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND MARYLAND

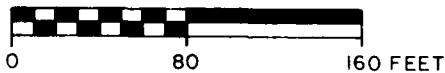
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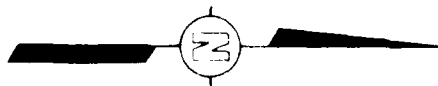


1	5	DRAWN BY	SH	CHECKED BY	RLC	25 SEP 81	DRAWING NUMBER	79-658-B9
			8-28-81	APPROVED BY	AJA	25 SEP 81		



2

2

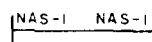


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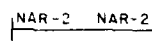
DWG NO ACI-P-1040-4, TITLED PLOT PLAN  
NEW ACID AREA, BY ATLAS CHEMICAL  
INDUSTRIES, INC DATED 2-10-71; SCALE  
1"=50'

N61,826.61  
E 56,106.56

## LEGEND



SEISMIC REFRACTION LINE



HORIZONTAL PROFILING  
RESISTIVITY LINE



GRAVITY MEASURING POINT



VERTICAL ELECTRICAL  
SOUNDING POINT



INDICATES LIMITS OF SUBSURFACE  
SEISMIC COVERAGE

## NOTES

- 1 SYMBOLS SHOWN IN LEGEND ARE SUPERIMPOSED AT THOSE POINTS WHERE MORE THAN ONE GEOPHYSICAL TECHNIQUE WILL BE EMPLOYED.
- 2 ARROWS ON VERTICAL ELECTRICAL SOUNDING POINTS INDICATE DIRECTION OF ELECTRODE EXPANSION.
- 3 CONTOURS ARE IN MILLIGALS  $\times 10^{-2}$ .

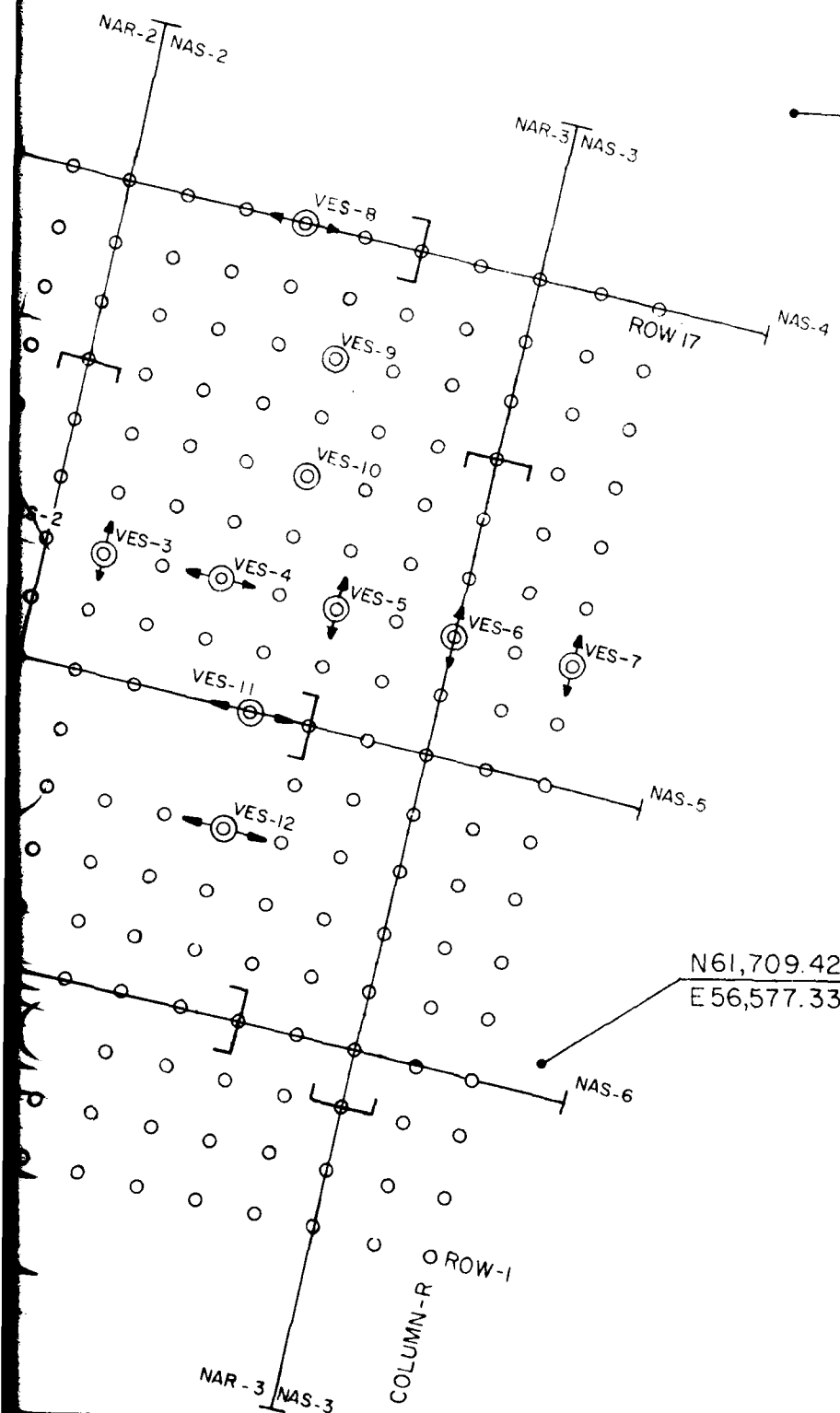
FIGURE 10

NEW ACID AREA  
BOUGUER ANOMALY GRAVITY MAP  
WITH FIRST-ORDER TREND REMOVED

PREPARED FOR

U S ARMY  
TOXIC AND HAZARDOUS MATERIALS AGENCY  
ABERDEEN PROVING GROUND, MARYLAND

DD FORM 100-10-1A





APPENDIX A  
BIBLIOGRAPHY

1

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## APPENDIX A

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# IDENTIFICATION

**DATE**  
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